AD-A131 123 RESEARCH TECHNIQUES IN WAVE PROPAGATION AND SCATTERING PROGRAM AND ABSTRA..(U) OHIO STATE UNIV COLUMBUS 1982 1/2

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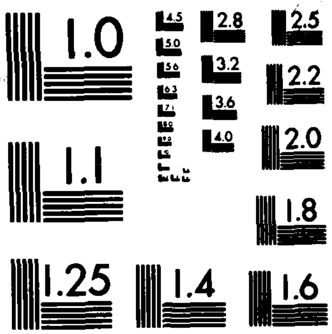

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RESEARCH TECHNIQUES
IN
WAVE PROPAGATION AND SCATTERING

Workshop/Symposium

October 18-21, 1982

ABSTRACTS

OSU

The Ohio State University

Sponsored by:

U.S. Army Research Office
U.S. Office of Naval Research
Center for Welding Research, O.S.U.
Department of Engineering Mechanics, O.S.U.

Host:

The Ohio State University
Columbus, Ohio

PROGRAM AND ABSTRACTS

RESEARCH TECHNIQUES IN WAVE PROPAGATION AND SCATTERING

Workshop/Symposium

October 18-21, 1982
The Ohio State University
Columbus, Ohio

Program Committee:

V.K. Varadan
V.V. Varadan
J.L. Gerber

Sponsors:

U.S. Army Research Office
U.S. Office of Naval Research
Center for Welding Research, O.S.U.
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ACKNOWLEDGEMENTS

We wish to thank the U.S. Army Research Office and the U.S. Office of Naval Research for their generous financial support. In particular, we would like to express our appreciation to Dr. Walter A. Flood of ARO and Dr. Richard G. Brandt of ONR for their active interest in and encouragement of this workshop.

In addition, we would like to acknowledge the financial support of the Center for Welding Research at the Ohio State University, and, especially, Drs. Karl F. Graff and Roy B. McCauley. Dr. Sunder H. Advani, Chairman of the Department of Engineering Mechanics at O.S.U., provided us with generous financial support and invaluable moral support. Facilities provided by the Ohio State University for the conduct of the workshop is also acknowledged.

SCOPE OF THE WORKSHOP/SYMPOSIUM

The aim of this conference is to bring together distinguished scientists who have pioneered the development of new analytical, numerical, and experimental techniques in the field of wave propagation and scattering and those who are more concerned with the application of these methods to problems of practical interest. The organizers hope to encourage a critical exchange of ideas between the "theorists" and the "practitioners."

A four day meeting is planned. The general lectures at the workshop will consist of detailed treatment of various analytical, numerical and experimental techniques. These lectures will be based on in-depth, pedagogical exposition of the techniques that will appear in the first volume of a handbook on acoustic, electromagnetic and elastic wave scattering. The Handbook will be a set of four volumes to be published by North Holland Publishing Company. In addition, the workshop will consist of presentations by other invited speakers on current applications of the techniques discussed in the general lectures. Selected presentations will appear in a special issue of the International Journal of Wave Motion. One session of the workshop will be devoted to Inverse Scattering Methods. Professor R.G. Newton will present a special lecture on an overview of the workshop and its relation to quantum mechanical scattering. Panel discussions are an important part of the workshop and we hope that all attendees will actively participate.

PROGRAM

Sunday, October 17, 1982

6-9 p.m.	RECEPTION AND REGISTRATION *Drake Union Patio*

Monday, October 18, 1982

8:00 a.m.	REGISTRATION *The Ohio Union Conference Theatre*
8:30	WELCOME AND INTRODUCTORY REMARKS *V.K. Varadan, The Ohio State University* *W.A. Flood, U.S. Army Research Office* *R.G. Brandt, U.S. Office of Naval Research* *S.H. Advani, The Ohio State University*
	SESSION I: LONG WAVELENGTH ASYMPTOTICS *Chairperson: J.D. Achenbach, Northwestern University*
8:50	RAYLEIGH SCATTERING--A SUMMARY *R.E. Kleinman, University of Delaware*
9:20	RAYLEIGH SCATTERING--APPLICATIONS AND EXTENSIONS *T.B.A. Senior, University of Michigan*
9:50	MATCHED ASYMPTOTIC EXPANSIONS APPLIED TO DIFFRACTION OF ELASTIC WAVES *S.K. Datta, University of Colorado* *F.J. Sabina, Instituto de Investigaciones en Matematicas, Mexico*
10:20	COFFEE BREAK
	SESSION II: MOMENT METHOD *Chairperson: C.L. Bennett, Sperry Research Center*
10:35	MOMENT METHOD APPROACH TO ELECTROMAGNETIC WAVE SCATTERING *R.F. Harrington, Syracuse University*
11:35	A MOMENT METHOD SOLUTION FOR SCATTERING FROM AN ELECTRIC SHELL *E.K. Miller, Lawrence Livermore National Laboratory*

Monday, October 18, 1982, cont.

11:55	APPLICATION OF METHOD OF MOMENTS TO ELASTODYNAMIC SCATTERING PROBLEMS *D.R. Wilton and L.W. Pearson, University of Mississippi* *K.J. Langenberg, Universatät des Saarlandes, FRG*
12:15	LUNCH
	SESSION III: HIGH FREQUENCY ASYMPTOTICS *Chairperson: C.H. Walter, The Ohio State University*
1:30 p.m.	A UNIFORM GTD APPROACH TO EM SCATTERING AND RADIATION *R.G. Kouyoumjian and P.H. Pathak, The Ohio State University*
2:20	RAY AND MODAL TECHNIQUES FOR TIME-HARMONIC AND TRANSIENT PROPAGATION ALONG, AND SCATTERING BY, CONVEX OBJECTS *L.B. Felsen and E. Heyman, Polytechnic Institute of New York*
3:20	EM DIFFRACTION BY A THIN DIELECTRIC HALF PLANE *P.H. Pathak and R. Rojas-Teran, The Ohio State University*
3:40	COFFEE BREAK
3:55	EDGE DIFFRACTION IN ACOUSTICS AND ELASTODYNAMICS *J.D. Achenbach, Northwestern University* *A.K. Gautesen, Iowa State University*
4:55	A GEOMETRICAL DIFFRACTION THEORY FOR THE SCATTERING OF ELASTIC WAVES FROM VOIDS *J.E. Gubernatis and R.J. Brind, Los Alamos National Laboratory* *J.D. Achenbach and R.D. Steinberg, Northwestern University*
5:15	ACOUSTIC SCATTERING BY WELDED RIBBED PLATES *S.I. Hayek and C. Seren, Pennsylvania State University*
6:00	COCKTAIL HOUR *The Faculty Club*
8:00	ELECTROSCIENCE LABORATORY TOUR

Tuesday, October 19, 1982

SESSION IV: TRANSFORM TECHNIQUES
Chairperson: W.M. Boerner, University of Illinois

8:30 a.m.	TRANSFORM TECHNIQUES FOR SOLVING ELECTROMAGNETIC SCATTERING PROBLEMS *R. Mittra and R. Kastner, University of Illinois*
9:30	TIME DOMAIN SOLUTIONS TO SCATTERING PROBLEMS *C.L. Bennett, Sperry Research Center*
10:00	COFFEE BREAK

SESSION V: T-MATRIX APPROACH
Chairperson: A. Boström, Institute of Theoretical Physics, Sweden

10:15	T-MATRIX APPROACH TO ACOUSTIC, ELECTROMAGNETIC AND ELASTIC WAVE SCATTERING *V.V. Varadan and V.K. Varadan, The Ohio State University*
11:15	ANALYTICAL CONSEQUENCES OF THE EXTENDED BOUNDARY CONDITION *P.C. Waterman, Center for Science and Technology, Inc.*
11:55	APPLICATIONS OF MOOT TO ELASTIC WAVE SCATTERING BY IRREGULAR DEFECTS *J.L. Opsal, Lawrence Livermore National Laboratory* *W.M. Visscher, Los Alamos National Laboratory*
12:10	SCATTERING BY ELASTIC SPHEROIDAL BODIES IMMERSED IN WATER *L. Green, M. Werby, R. Hackman, and L. Flax, Naval Coastal Systems Center*
12:25	LUNCH

SESSION VI: EXPERIMENTAL TECHNIQUES
Chairperson: N.L. Basdekas, Office of Naval Research

1:30 p.m.	EXPERIMENTAL METHODS IN ACOUSTIC SCATTERING *S.K. Numrich and L.R. Dragonette, Naval Research Laboratory*
2:10	NEAR-FIELD SCATTERING MEASUREMENTS *C.E. Ryan, Georgia Institute of Technology*

Tuesday, October 19, 1982, cont.

2:50	EXPERIMENTAL STUDIES OF ELASTIC WAVE SCATTERING *B.R. Tittmann, Rockwell International Science Center* *L. Adler, The Ohio State University*
3:30	COFFEE BREAK
3:45	USE OF ULTRASONIC DIFFRACTION CORRECTIONS TO RELATE MEASUREMENTS THROUGH LIQUID-SOLID INTERFACES TO INFINITE MEDIUM SCATTERING AMPLITUDES *R.B. Thompson, T.A. Gray, D.K. Hsu, and J.H. Rose, Ames Laboratory and Iowa State University*
4:05	PANEL DISCUSSION *Moderator: R.E. Kleinman, University of Delaware* *Panel Members: R.F. Harrington, P.C. Waterman, J.D. Achenbach, L.B. Felsen, R.B. Thompson*
5:30	TOUR OF CENTER FOR WELDING RESEARCH AND THE ULTRASONICS LABORATORY
8-10 p.m.	POSTER SESSION/ADDED SESSION *The Ohio Union Conference Theatre*

Wednesday, October 20, 1982

	SESSION VII: FINITE ELEMENT APPROACH/HYBRID TECHNIQUES *Chairperson: D.O. Thompson, Ames Laboratory and Iowa State University*
8:30 a.m.	UNIMOMENT METHOD FOR ELECTROMAGNETIC WAVE SCATTERING *K.K. Mei and T.M. Kvam, University of California, Berkeley*
9:30	A HYBRID FINITE ELEMENT - EIGENFUNCTION METHOD FOR ELASTIC WAVE SCATTERING PROBLEMS *V.K. Varadan, V.V. Varadan, and J.H. Su, The Ohio State University*

Wednesday, October 20, 1982, cont.

10:00		FINITE ELEMENT - BOUNDARY INTEGRAL FORMULATION FOR ELECTROMAGNETIC SCATTERING *M.A. Morgan, Naval Postgraduate School* *C.H. Chen, COMSAT Laboratories* *S.C. Hill and P.W. Barber, University of Utah*
10:20		A NEW HYBRID T-MATRIX - BOUNDARY ELEMENT APPROACH FOR SCATTERING OF WAVES BY ELASTIC SHELLS IN WATER *K. Eswaran, V.K. Varadan, and V.V. Varadan, The Ohio State University*
10:40		COFFEE BREAK
		SESSION VIII: OTHER ASYMPTOTIC/NUMERICAL APPROACHES *Chairperson: G.S. Brown, Applied Science Associates*
10:55		EXPLOITING THE LIMITING AMPLITUDE PRINCIPLE TO SOLVE SCATTERING PROBLEMS *G.A. Kriegsmann, Northwestern University*
11:15		COMPARISON OF THE KIRCHHOFF APPROXIMATION WITH EXACT SCATTERING THEORY FOR CRACKS *A.N. Norris, Northwestern University*
11:35		ELASTIC WAVE SCATTERING BY SURFACE CRACKS *W.M. Visscher, Los Alamos National Laboratory*
11:50		THE APPLICATION OF ITERATIVE METHODS FOR THE SOLUTION OF SCATTERING PROBLEMS *T.K. Sarkar, S.M. Rao, and S.A. Dianat, Rochester Institute of Technology*
12:10		LUNCH
		SESSION IX: BOUNDARY INTEGRAL TECHNIQUES AND GUIDED WAVES *Chairperson: T.A. Seliga, The Ohio State University*
1:30 p.m.		THREE-DIMENSIONAL SCATTERING OF PULSED ELASTIC WAVES BY A PENETRABLE OBSTACLE (INTEGRAL-EQUATION TECHNIQUE) *A.T. de Hoop, Delft Institute of Technology, The Netherlands*

Wednesday, October 20, 1982, cont.

2:20	SPECIAL RESPONSE WAVEFORMS - CAVITY AND RELATED STRUCTURES *D.L. Moffatt, N. Wang, and C.Y. Lai, The Ohio State University*
2:40	AN EXTENDED BOUNDARY CONDITION METHOD FOR ANALYZING MODES OF DIELECTRIC WAVEGUIDES *N. Morita, Osaka University, Japan*
3:00	ELECTROMAGNETIC WAVES IN A CYLINDRICAL WAVEGUIDE WITH PERIODICALLY VARYING CROSS SECTION *A. Boström, Institute of Theoretical Physics, Sweden*
3:20	COFFEE BREAK
	SESSION X: SPECIAL LECTURE *Chairperson: J. Chandra, Army Research Office*
3:35	SOME ASPECTS OF RECENT WORK IN QUANTUM PARTICLE SCATTERING AND ITS RELATION TO WAVE SCATTERING *R.G. Newton, Indiana University*
4:35	PANEL DISCUSSION *Moderator: A.T. de Hoop, Delft Institute of Technology* *Panel Members: R.G. Kouyoumjian, R. Mittra, W.M. Boerner, R.G. Newton, K.K. Mei*
6:15	COCKTAIL HOUR *The Ohio Union Terrace Lounge*
7:30	BANQUET *The Ohio Union East Ballroom*

Thursday, October 21, 1982

	SESSION XI: INVERSE SCATTERING *Chairperson: C. Holland, Office of Naval Research*
8:30 a.m.	INVERSE MODELLING IN REMOTE SENSING *W.M. Boerner, University of Illinois, Chicago*

Thursday, October 21, 1982, cont.

9:30	ELASTIC WAVE INVERSE BORN APPROXIMATION--RECENT ADVANCES *J.H. Rose, Ames Laboratory and Iowa State University*
10:00	ELASTIC WAVE INVERSE SCATTERING THEORY *A.J. Devaney, Schlumberger-Doll Research*
10:30	COFFEE BREAK
10:45	SOME RECENT RESULTS IN PROBABILISTIC INVERSE SCATTERING *J.M. Richardson and K.A. Marsh, Rockwell International Science Center*
11:05	RIGOROUS INVERSE SCATTERING THEORY FOR THE TIME-DEPENDENT WAVE EQUATION *B. DeFacio, University of Missouri, Columbia*
11:25	IMAGING TECHNIQUES IN ELECTROMAGNETICS *J.D. Young, The Ohio State University*
11:45	THE INVERSE SCATTERING PROBLEM OF THE DUAL POLARIZATION DIFFERENTIAL REFLECTIVITY RADAR TECHNIQUE *T.A. Seliga and K. Aydin, The Ohio State University* *V.N. Bringi, Colorado State University*
12:05	LUNCH
	SESSION XII: SPECIAL TOPICS *Chairperson: J. Greenberg, The Ohio State University*
1:15 p.m.	WAVEFRONT FIELDS IN THE SCATTERING OF ELASTIC WAVES BY SURFACE-BREAKING AND SUB-SURFACE CRACKS *J. Miklowitz, California Institute of Technology*
2:15	PANEL DISCUSSION: FUTURE RESEARCH IN WAVE PROPAGATION AND SCATTERING *Panel Members: W.A. Flood, U.S. Army Research Office; R.G. Brandt, N.L. Basdekas, and C. Holland, U.S. Office of Naval Research*
3:15	COFFEE BREAK
3:30	ADJOURN

ABSTRACTS

Mon., 8:50 a.m.

RAYLEIGH SCATTERING--A SUMMARY

R.E. Kleinman
The University of Delaware
Newark, DE 19711

T.B.A. Senior
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The determination of the first or Rayleigh term in the far field coefficient for a variety of scattering problems is considered. The unifying thread is the use of polarizability tensors to characterize the Rayleigh term in the far field coefficient. These tensors, which are symmetric for isotropic scatterers, enable the scattered field to be expressed in terms of quantities which depend only on the geometry and constitutive parameters of the scatterer. Methods for finding these tensor elements as solutions of integral equations are presented and numerical results are given which show the dependence of these quantities on the geometry of the scatterer. Scatterers of both finite non zero volume and zero volume are considered in the perfectly conducting case. For penetrable scatterers of finite volume results are presented for pure (lossless) dielectrics as well as dispersive material, lossy dielectrics and plasmas. Also presented are results for Rayleigh scattering of acoustic waves using the mechanism of polarizability tensors.

NOTES

Mon., 9:20 a.m.

RAYLEIGH SCATTERING--APPLICATIONS AND EXTENSIONS

T.B.A. Senior
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Some applications and extensions of the basic theory presented in the Chapter on Rayleigh scattering are discussed.

The Rayleigh term is simply the leading term in low frequency expansion of the far field in powers of ω r k, where k is the wavenumber of the surrounding medium. For an electrically small body the first term alone may serve to adequately approximate the behavior, and for dielectric bodies the results are widely used in studies of atmospheric scattering and absorption at frequencies in the microwave, infrared and, possibly, optical regimes. Some recent investigations are described, including the effect of particle shape on material resonance phenomena. In principle at least, techniques similar to those used to determine the Rayleigh term can also be employed to develop succeeding terms in the low frequency expansion. The procedure is straightforward in acoustics, but in electromagnetics difficulties occur. These are both practical and fundamental, and are illustrated in the case of a metallic body.

NOTES

Mon., 9:50 a.m.

MATCHED ASYMPTOTIC EXPANSIONS APPLIED TO DIFFRACTION OF ELASTIC WAVES

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04510 Mexico, D.F.

Diffraction of elastic waves in two and three dimensions has been studied when the wavelength of the incident disturbance is long. It is shown that the scattered field is obtained as the solution of a singular perturbation problem. The technique of matched asymptotic expansions has been used to find expansions of the scattered field both near and far from the scattering object in terms of a small parameter which is the ratio of a characteristic dimension of the object and the wavelength. The application of the technique is illustrated by first solving a simple two dimensional problem of scattering of a plane horizontally polarized shear wave by a circular cylindrical cavity. Details of the matching principle are discussed here. Once these are understood it is shown how the technique can be used with relative ease to solve more complicated scalar and vector problems.

NOTES

Mon., 10:35 a.m.

MOMENT METHOD APPROACH TO ELECTROMAGNETIC WAVE SCATTERING

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Syracuse, NY 13210

The method of moments is a general procedure for reducing a functional equation to a matrix equation. Once the matrix equation is obtained, the methods of linear algebra can be used to effect a solution. Various specializations of the method of moments are Galerkin's method, point matching or collocation, and the least squares method. Other procedures equivalent to the moment method are the method of weighted residuals, the method of projections, the Petrov-Galerkin method, and the Rayleigh-Ritz variational method. The stationary character of the moment method solution, and the perturbational-variational method, are discussed.

The method of moments is applied to obtain solutions to the two-dimensional and three-dimensional Laplace's equation. In the two-dimensional case, boundary conditions of the Dirichlet type, the Neumann type, the Cauchy type, and mixed type are considered. In the three-dimensional case, only rotationally symmetric potentials subject to Dirichlet boundary conditions are considered explicitly. Examples of the solution are given, and comparisons to exact solutions are made when possible.

The general problem of electromagnetic scattering by a perfectly conducting body is considered. Integral equations of the E-field type, the H-field type, and of the combined-field type are examined. It is shown that the first two types of equations are singular at frequencies for which the surface of the body, when covered by a perfect electric conductor, forms a resonant cavity. The third type of equation does not have this defect. This means that the moment solutions to the E-field and H-field equations degenerate in the vicinity of the resonant frequency of the cavity, while the moment solution to the combined-field equation does not.

The E-field equation is used to obtain solutions for radiation and scattering from conducting wires and from bodies of revolution. For the wire case, pulse functions are used for expansion and point matching for testing. For the body of revolution case, a Galerkin solution is used with sinusoidal functions in the azimuthal angle and triangle functions in the contour length variable. Formulas for the computation of the current on the body and the radiation field are derived. Comparison of computations made with the moment method to those made with other methods is made for some representative cases.

NOTES

Mon., 11:35 a.m.

A MOMENT-METHOD SOLUTION FOR SCATTERING FROM AN ELECTRIC SHELL

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Livermore, CA 94550

As in electromagnetic (EM) scattering, it is possible to formulate the acoustic problem as an integral equation for the sources induced on a scattering surface. Solution for these sources then provides the means for obtaining the scattered field from an integral over that surface. For those cases where the acoustic problem is closely analogous to the EM one, the formulation and numerical treatment are correspondingly similar. Examples are provided by rigid and free-surface acoustic scatterers whose treatments are essentially identical to EM scattering from perfect magnetic and perfect electric conductors, respectively. Early work in numerical acoustics [1,2,3] illustrates this fact.

But, the more general EM and acoustics problem is that wherein the scatterer is penetrable, in which case the incident field can induce not only surface sources but interior fields as well. It is in this situation that the acoustics problem can become generally more complicated than its EM counterpart. Whereas the EM problem involves only two polarizations of basically the same kind of field for most media of interest, the acoustic problem frequently involves an elastic scatterer (and sometimes also an elastic medium). The elasticity leads to both shear-wave and compressional-wave interior fields, whose mutual presence can give rise to a very complex scattering behavior, and significantly complicates the formulation and subsequent solution.

A relatively straightforward approach to objects having penetrable interiors is to use a Green's function for an infinite medium having the same properties as the object's interior, if one is available. Expressions can be written for the interior and exterior fields in terms of their respective Green's functions and surface integrals over the object. It is then possible to derive integral equations for the induced surface sources by letting the observation points approach the surface from either side while imposing the required boundary conditions at the object-medium interface. However, this approach is not always suitable even if a Green's function is available. An inhomogeneous object, for example, requires a volumetric-integral treatment, in which case an approach based on a differential equation is usually preferable.

Various approximations may be used to reduce the complexity of the solution for the penetrable scatterer. In electromagnetics, it is common to use the concept of a surface impedance, whereby the tangential electric field is expressed in terms of the tangential magnetic field multiplied by an impedance which is determined by the interior medium and possibly the radius of curvature. A further approximation results from expressing both fields as the sum of incident and reflected components, where again the reflection coefficient is determined by the object parameters.

Corresponding approximations can be appropriate in acoustic problems. One problem of interest is that of scattering from an elastic shell located in a fluid medium. For scattering from thin shells in the linear-response regime [4], it is possible to greatly simplify the problem by using the "thin-shell" approximation in which the normal stresses and bending moments can be neglected. In this case, the interior problem simplifies to a differential equation of motion for the shell. When this is combined with an integral equation for the exterior scattered field, a coupled integro-differential equation is obtained.

In this paper, the analytical development of a solution to the problem of scattering from fluid-immersed, thin, elastic, spherical shells is given. The numerical treatment is described and representative results which validate the treatment and illustrate physical behavior are presented. Consideration is given to extending the treatment to non-spherical shells (axi-symmetric, for example).

References:

[1] Mitzner, K.M. (1967), "Numerical Solution for Transient Scattering from a Hard Surface of Arbitrary Shape-Retarded Potential Technique," Journal of the Acoustical Society of America, 42, p. 391.

[2] Schenck, H.A. (1968), "Improved Integral Formulation for Acoustic Radiation Problems," Journal of the Acoustical Society of America, 44, No. 1, p. 41.

[3] Fenlon, F.H. (1969), "Calculation of the Acoustic Radiation Field at the Surface of a Finite Cylinder by the Method of Weighted Residuals," Proc. IEEE, 57, p. 291.

[4] Burke, G.J., E.K. Miller, A.J. Poggio, G.M. Pjerrou, B.J. Maxum and W. Meecham (1972), "An Integro-Differential Equation Approach to Acoustic Scattering from Fluid-Immersed Elastic Bodies," J. Comp. Phy., 10, pp. 22-39.

NOTES

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Mon., 11:55 a.m.

APPLICATION OF METHOD OF MOMENTS
TO ELASTODYNAMIC SCATTERING PROBLEMS

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The method of moments is a general procedure for the numerical solution of linear functional equations. In its most general form it encompasses practically all methods which convert such equations into an approximating system of linear equations. The term as used in electromagnetics, however, usually refers to a more restricted form of the procedure which is equivalent to the so-called boundary element method of mechanics. In electromagnetics the method of moments has developed into an indispensable tool for analysis of radiation (antenna) and scattering problems.

These problems are usually formulated as integral or integro-differential equations with unknown surface fields. It has been found highly desirable that solution procedures formulated for such problems be not only numerically stable and efficient, but also simple and general. An excellent compromise between these sometimes conflicting requirements is usually afforded by the use of subdomain basis and testing (weighting) functions to represent unknown surface fields and to enforce equality in a weighted average sense, respectively. In addition, particularly in multi-dimensional problems, judicious approximations are often made to minimize the numerical quadrature required.

This paper is intended to illustrate the adaptation of the foregoing techniques and considerations to problems in elastodynamic scattering. Simple cavity problems are considered and integral equations in a form suitable for numerical solution by the method of moments are derived. Modeling of cavity boundary surfaces is discussed as are considerations involved in the choice of basis and testing functions. Singularities in the integral equation kernel are investigated and techniques for the numerical handling of such singularities are discussed.

NOTES

Mon., 1:30 p.m.

A UNIFORM GTD APPROACH TO EM SCATTERING AND RADIATION

R.G. Kouyoumjian and P.H. Pathak
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In recent years the geometrical theory of diffraction (GTD) has developed rapidly as a practical tool for calculating the radiation from complex shapes. At the present time it has progressed beyond the treatment of simple examples to the construction of user-oriented computer programs for antenna and scattering problems of engineering interest.

When a radiating object is large in terms of a wavelength, the scattering and diffraction are found to be essentially local phenomena associated with specific parts of the object, e.g., points of specular reflection, edges, the shadow boundaries on convex surfaces, etc. The GTD is a high-frequency approach which employs rays in a systematic way to describe these phenomena. It is an extension of geometrical optics in which diffracted rays are introduced through a generalization of Fermat's principle. In its original form it failed at shadow and reflection boundaries; however this deficiency has been overcome with the development of the uniform GTD (UTD), which can be used to obtain the correct, smooth, continuous fields at these boundaries.

In this paper the use of the UTD will be illustrated by applying it to calculate the radiation from two dimensional geometries with edges and curved surfaces. The thick edge is chosen to show how to calculate single edge diffraction, multiple edge diffraction, and slope diffraction, which is important when the field incident at the edge has a rapid spatial variation. For diffraction by a smooth, convex surface, the circular cylinder is chosen to illustrate the calculation of the diffracted field induced at a shadow boundary, the generalized reflected field at the point of specular reflection, and the slope diffracted field in cases where the incident field has a rapid spatial variation.

In conclusion the generalization of the method to three dimensional problems is described briefly, the application to complex shapes is illustrated, and some recent extensions of the UTD to surfaces which are non-conducting are mentioned.

NOTES

Mon., 2:20 p.m.

RAY AND MODAL TECHNIQUES FOR TIME-HARMONIC AND TRANSIENT PROPAGATION ALONG, AND SCATTERING BY, CONVEX OBJECTS

L.B. Felsen and E. Heyman
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At high frequencies, phenomena of acoustic, electromagnetic or elastic propagation along, and scatteringy by, smoothly curved convex objects are treated effectively by ray methods. These methods can be employed to characterize not only the time-harmonic and transient fields reflected by the object but also the guided mode fields traveling around the object. The source-free eigenstates representing the surface guided modes are described in terms of ray congruences which must satisfy closure conditions not required of source-excited fields. Since the surface guided modes leak energy as they progress, the congruences which synthesize them are comprised of complex rays. Accordingly, the complete ray description of the scattering properties of smooth convex targets involves real rays for reflected fields and complex modal rays for the fields guided along the target surface. These concepts are illustrated first for the two-dimensional canonical problem of time-harmonic propagation along a circular boundary, and are generalized thereafter to boundaries with arbitrary convex shape. Complex ray theory is introduced and then applied to the study of guided modes. Complex caustics play a fundamental role in furnishing the complex ray congruences which must be combined self-consistently in traveling modal fields of the creeping wave, leaky wave or leaky surface wave type that can be supported on convex boundaries with different physical characteristics. The distinguishing feature of these various wave types is the location of the modal caustic with respect to the boundary. To account for the angular periodicity of the modal fields when the target is a closed cylinder, an additional constraint, on the allowable frequencies, must be imposed to generate standing wave solutions. The resulting resonant modes play an important role in the description of the transient response of the object where they furnish the damped oscillations that form the basis for the singularity expansion method (SEM). The transient problem per se is illustrated by determining the electromagnetic or acoustic surface fields excited by an impulsive line source on the surface of a perfectly conducting or acoustically hard cylindrical boundary. Alternative field representations are utilized which characterize the surface fields either in terms of transient traveling (creeping) waves or SEM resonances, and which also clarify the relation between these. Hybrid formulations are then developed to combine traveling and resonant fields within a single framework so as to maximize the advantages of tracking behind the wavefronts of

the creeping waves at early times (high frequency regime) and employing SEM resonances at later times (low-frequency regime). From these considerations, there emerges a self-consistent and effective treatment of a broad class of time-harmonic and transient scattering problems.

NOTES

Mon., 3:20 p.m.

EM DIFFRACTION BY A THIN DIELECTRIC HALF PLANE

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Columbus, OH 43210

A uniform geometrical theory of diffraction (UTD) analysis is presented for the problem of electromagnetic (EM) diffraction by a thin dielectric half plane. The excitation for this problem can be either a plane, or a surface wave field. The total solution to this problem is constructed via a superposition of the solutions to the problems of EM plane (or surface) wave diffraction by configurations involving perfectly conducting electric and magnetic wall bisections of the dielectric half plane, respectively. The latter solutions are in turn obtained via the Wiener-Hopf procedure when the dielectric half plane is assumed to be sufficiently thin. The Wiener-Hopf factorization functions that are present in the solution are relatively simple and contain integrals over finite limits. The general form of the solution is quite similar to the UTD solution for the perfectly-conducting half plane diffraction problem; furthermore, it suggests an ansatz for extending the analysis to treat the diffraction by a moderately thick dielectric half plane. Both, TE_z and TM_z cases are considered in this work; here the subscript z refers to the coordinate along the edge of the dielectric half plane. Some examples illustrating the accuracy of the present solution will be illustrated.

NOTES

Mon., 3:55 p.m.

EDGE DIFFRACTION IN ACOUSTICS AND ELASTODYNAMICS

J.D. Achenbach
Department of Civil Engineering
Northwestern University
Evanston, IL 60201

A.K. Gautesen
Ames Laboratory and
Department of Mathematics
Ames, IA 50011

The geometrical theory of edge diffraction for acoustics and elastodynamics is presented, with the emphasis placed on elastodynamics.

The eikonal and transport equations governing asymptotic solutions of the reduced wave equation are developed. For homogeneous isotropic mediums, the solutions to the eikonal equation (a statement of Fermat's principle) and the leading order transport equation are given. These solutions are used to construct asymptotic solutions to the equations of linear elastodynamics. A discussion of the reflection of asymptotic waves from a plane traction-free surface is given as an example.

The canonical problems for edge diffraction of waves in elastic solids and of scalar waves are discussed and the corresponding theories of edge diffraction are presented. For waves in elastic solids, the theories for the diffraction of Rayleigh surface-wave rays and their subsequent diffraction of body waves are included. A ray analysis of diffraction by a penny shaped crack is also given. The geometrical theory of diffraction yields discontinuities at shadow boundaries, and uniform asymptotic theory which removes these discontinuities is presented.

As an example of the geometrical theory of edge diffraction, the two-dimensional problem of scattering of a plane wave by a crack is analyzed in detail. To give some perspective on the roles of boundary and edge conditions in the geometrical theory of diffraction, the construction of the solution to the equations of linear elastodynamics by the method of matched asymptotic expansions is discussed.

NOTES

Mon., 4:55 p.m.

A GEOMETRICAL DIFFRACTION THEORY FOR THE SCATTERING OF ELASTIC WAVES FROM VOIDS

J.E. Gubernatis
Los Alamos National Laboratory
Los Alamos, NM 87544

J.D. Achenbach, R.J. Brind, and R.D. Steinberg
Northwestern University
Evanston, IL 60201

We are investigating the importance of the creeping wave contribution to the scattering of a time-harmonic, longitudinally polarized plane wave from circular, elliptical, spherical and spheroidal voids. In the process, we have defined a procedure for using the creeping wave analysis for the circular void (a scatter of fixed radius of curvature in two-dimensions) for calculating the scattering from an elliptical void (a scatterer of variable radius of curvature in two dimensions), and spherical and spheroidal voids (scatterers fixed and variable radius of curvature in three dimensions). Besides comparing the creeping wave predictions based on exact expressions and their asymptotic forms, we have also calculated the geometrical optics and Kirchhoff approximations and have evaluated their predictions by comparing them with calculations of the exact results for cylinders and spheroids and with the Method of Optimal Truncation results for ellipses and spheroids. For wavelengths comparable to the scatterer size, we have found that creeping wave effects are important, the scattered results are sensitive to how the creeping waves on shadowed portions of the scatterer surface is approximated, the asymptotic forms of the creeping waves give inaccurate results, and the best predictions of the scattering results from using a hybrid theory. This hybrid theory is one in which the creeping waves are used to compute the fields on the scatterer in the shadow zone and then used in a representation integral to compute the scattering.

NOTES

Mon., 5:15 p.m.

ACOUSTIC SCATTERING BY WELDED RIBBED PLATES

S.I. Hayek and C. Seren
The Pennsylvania State University
University Park, PA 16802

The acoustic scattering from welded joints on elastic plates is investigated. An infinite elastic plate is welded to a finite length rib where the former is in contact with an acoustic medium on the unwelded side. The welded rib and the back of the infinite plate is in vacuo. The solution for the scattered pressure is obtained for a plane wave incidence by use of integral transforms and asymptotic methods. Various types of welded joints are considered, which influences the boundary conditions for the shears and moments at the joint. Emphasis is placed on the scattered pressure in the farfield and in the nearfield of the welded joint. Asymptotic techniques which account for the poles of the scattering function were employed to obtain the solution in the nearfield of the plate but in the farfield of the joint itself. The solution assesses the influence of the elastic plate on the propagation of acoustic waves at grazing angles. Experimental data were obtained on the scattered pressure from an elastic plate welded to two types of ribs in the frequency range 15 - 100 kHz.

NOTES

Tues., 8:30 a.m.

TRANSFORM TECHNIQUES FOR SOLVING ELECTROMAGNETIC SCATTERING PROBLEMS

R. Mittra and R. Kastner
University of Illinois
Urbana, IL 60801

Conventional approaches to solving electromagnetic radiation and scattering problems involve the use of either the matrix methods for low frequencies or asymptotic techniques, e.g., ray methods, for high frequencies. When the size of the scatterer is on the order of $(1\lambda)^3$ or more, the moment method, which results in a matrix formulation of the boundary-value problem, becomes severely limited because of prohibitive cost and computer storage requirements associated with the generation and inversion of a large matrix. The ray methods, on the other hand, are largely limited to frequencies above the resonance range and to scatterers that are perfect conductors. For these reasons, the need for a general approach to solving scattering problems in the intermediate or resonance frequency range, and for arbitrary scatterers including inhomogeneous dielectric bodies, has long been recognized. The purpose of this paper is to describe the spectral-domain method, which is based on the use of the two-dimensional Fourier transform technique and which has been found to exhibit good potential for attacking the problem of scattering from arbitrary bodies.

One of the most important approaches for solving a class of planar problems is the Spectral-Iterative Technique (SIT). However, the spectral approach is by no means limited to planar bodies because an arbitrary scattering problem can be formulated by using an aggregate of planar current distributions. This modeling makes it possible to extend the capabilities of the spectral-domain approach to arbitrarily-shaped, perfectly conducting, or lossy dielectric scatterers, all of which are modeled by a set of parallel, planar distributions of induced current.

A unique built-in feature of the spectral iteration technique is its ability to assess the accuracy of the solution as it provides a boundary-condition check at each stage of iteration. Another important feature of the spectral-iterative method is that it is capable of handling a rather large number of unknowns, on the order of 2,000 or more, far beyond the reach of the matrix methods. This feature enables one to attack moderate-to-large size scatterers, which were previously considered to be unmanageably large and beyond the scope of the Moment Method and other available techniques.

NOTES

Tues., 9:30 a.m.

TIME-DOMAIN SOLUTION FOR SCATTERING PROBLEMS

C. Leonard Bennett
Sperry Research Center
Sudbury, MA 01776

Over the past fifteen years, time-domain solution techniques have been developed for and applied to numerous electromagnetic and acoustic scattering problems. This paper provides a review of the space-time integral equation approach to the solution of these problems and presents some representative examples of its application. Both the direct and the inverse scattering problems are considered.

The space-time integral equation approach to the direct scattering problem consists of (1) forming a time-domain integral equation for the fields on the surface of the target; (2) representing the target geometry in terms of surface patches that cover the target; (3) numerically solving the integral equation for the field at the center of the patch by marching-on-in-time; and (4) numerically computing the field at any point in space using the surface fields. This technique has been successfully applied to conducting thin wires, thin plates, solid bodies either by themselves or with wires or fins attached, and to dielectric solid bodies for the electromagnetic case. The technique has also been successfully applied to sound hard, sound soft, and to fluid bodies in the acoustic case.

The space-time integral equation approach has also been successfully applied to the inverse scattering problem for solid conducting bodies with rotational symmetry. The integral equation in this case relates the incident wave, the far scattered wave, and the target geometry in such a way that the target geometry can be numerically obtained by stepping-on-in-time the integral equation.

NOTES

Tues., 10:15 a.m.

T-MATRIX APPROACH TO ACOUSTIC, ELECTROMAGNETIC AND ELASTIC WAVE SCATTERING

V.V. Varadan and V.K. Varadan
Wave Propagation Group
Department of Engineering Mechanics
The Ohio State University
Columbus, OH 43210

A survey of the T-matrix method as proposed by Waterman for acoustic and electromagnetic wave scattering problems which has since been extended to elastic wave problems, will be presented. This method, which invokes the extinction theorem as an extended boundary condition, is an attractive one since it presents a unified approach to all types of classical field problems. Beginning with the integral representation of the fields, the T-matrix of a single scatterer will be derived in each case. Extensions to multiple and layered scatterers as well as to geometries involving nearby boundaries will be discussed using integral representation as well as a self-consistent approach. The special case of problems involving a solid-fluid interface will also be discussed since this will involve a coupling of the acoustic and elastodynamic fields. Symmetry and unitarity properties of the scattering matrix resulting from reciprocity and conservation of energy will be discussed in all cases. Various possible choice of basis functions for representing the surface and interior fields will be considered. Numerical results will be presented as appropriate.

NOTES

Tues., 11:15 a.m.

ANALYTICAL CONSEQUENCES OF THE EXTENDED BOUNDARY CONDITION

P.C. Waterman
Center for Science and Technology, Inc.
Burlington, MA 01803

The extended boundary condition (EBC) leads, in the usual manner, to a set of equations specifying the values of integrals of products of the wave functions with the unknown surface fields. For Dirichlet boundary conditions on a class of smooth cylinders, an asymptotic description is then found for the Fourier coefficients of the higher-order wave functions ($n >> 1$) in terms of a one-dimensional diffusion model, in which n plays the role of time. For the limiting case of potential theory, these results lead to the ansatz that the Fourier expansion of the surface charge density converges exactly geometrically, and a secular procedure can then be defined that determines the decay rate.

In numerical illustrations, by correcting the truncated equations using the known decay rate of the coefficients not kept (the "asymptotic anticipation" method of Neureuther and Zaki), the early coefficients are found to settle down immediately vs. truncation size, and to exhibit the correct decay rate (in one case over more than five orders of magnitude). Using the asymptotic forms of the matrix elements, it is also possible to check all the remaining EBC equations, including the "last" one (that equation obtained in the limit $n \to \infty$); we find them to be satisfied within a few percent.

For three-dimensional problems, asymptotic behavior of the wave functions can be described using expansion in Legendre polynomials and a two-dimensional diffusion model. Because the asymptotic formulas for wave functions and potential functions are identical (to within a normalization constant), we anticipate that the above techniques should apply also to scattering problems, with relatively minor modifications.

NOTES

Tues., 11:55 a.m.

APPLICATIONS OF MOOT TO ELASTIC WAVE SCATTERING BY IRREGULAR DEFECTS

J.L. Opsal
Lawrence Livermore National Laboratory
Livermore, CA 94550

W.M. Visscher
Los Alamos National Laboratory
Los Alamos, NM 87544

The method of optimal truncation (MOOT), a least squares boundary residual method for doing scattering calculations, has been successfully applied to a number of interesting elastic wave scatterers of fundamental and practical significance. These include irregular shaped voids with corners and crack-like features, flat circular cracks, and cracked spherical inclusions. Following a brief theoretical description of MOOT, we will present some results of these calculations that illustrate the method's broad range of applicability as well as its accuracy and rate of convergence. Practical considerations related to computer storage and time will also be discussed.

NOTES

Tues., 12:10 p.m.

SCATTERING BY ELASTIC SPHEROIDAL BODIES IMMERSED IN WATER

L. Green, M. Werby, R. Hackman, and L. Flax
Naval Coastal Systems Center
Panama City, FL 32406

The scattering of acoustic waves by non-spherical elastic bodies immersed in a fluid is a topic of considerable interest. In this paper, the T-Matrix approach is applied to the scattering of plane acoustic waves incident upon elastic spheroidal bodies immersed in water. Both spheroidal solids and shells will be considered. Various aspect ratios and shell thicknesses are treated. The wavenumber of the incident acoustic wave satisfies $5 \leq kL/2 \leq 12$ where k is the wavenumber of the incident acoustic wave and L is the length of the major axis of the body.

Incidental to the calculation of the scattered field, we will consider different types of expansion functions for the surface currents. The rate of convergence of the elements of the T-Matrix and the form function will be presented as a function of the type of surface expansion used.

Additionally a new procedure for the calculation of the T-Matrix, which is applicable to elastic shells, will be presented. The technique, in addition to satisfying symmetry and unitarity conditions, proves to be more numerically stable and less time consuming than the conventional method.

NOTES

Tues., 1:30 p.m.

EXPERIMENTAL METHODS IN ACOUSTIC SCATTERING

S.K. Numrich and L.R. Dragonette
Naval Research Laboratory
Washington, DC 20375

Underwater acoustic scattering measurements are an integral part of the acoustic target characteristics program at the Naval Research Laboratory. The Laboratory has investigated a variety of phenomena, which include among others the scattering from canonical shapes; creeping and circumferential waves; multiple scattering; long range determination of elastic constants; and flaw detection. The methods employed have included both narrow and broadband hydrophone measurements and visualization techniques. Descriptions of the experimental facilities and techniques are presented, as well as examples emphasizing recent results.

NOTES

Tues., 2:10 p.m.

NEAR-FIELD SCATTERING MEASUREMENTS

Charles E. Ryan, Jr.
Georgia Institute of Technology
Atlanta, GA 30332

This lecture will present a review of electromagnetic near-field measurements with emphasis on scattering measurements. Topics which will be discussed include: (1) instrumentation; (2) bistatic scattering measurements of model targets; (3) forward scattering measurements of cylinders and support towers; (4) scattering measurements of reflector antenna aperture perturbations caused by damage; and (5) near-field measurements to determine aircraft antenna performance. In addition, aspects of numerical processing will be addressed including methods to enhance the field-of-view of planar measurements of non-aperture limited fields.

NOTES

Tues., 2:50 p.m.

EXPERIMENTAL STUDIES OF ELASTIC WAVE SCATTERING

Bernhard R. Tittmann
Rockwell International Science Center
Thousand Oaks, CA 91360

Laszlo Adler
The Ohio State University
Columbus, OH 43210

This review presents recent experimental results on the scattering of elastic waves from single obstacles of various shapes embedded in titanium. The report describes briefly the experimental approach including the sample preparation and measurement technique by digitized ultrasonic spectrum analysis. The obstacles are principally voids ranging in shape from elliptical cracks to spheroids. The information falls into two classes depending on ka: $1 \leqq ka \leqq 4$ and $2 \leqq ka \leqq 20$, where k is the wave number and a is the effective obstacle radius. The results are presented as amplitude spectra comparing the experimental data with the calculations from various theoretical approaches, including physical elastodynamic theory, matrix theory, and distorted wave Born approximation.

NOTES

Tues., 3:45 p.m.

USE OF ULTRASONIC DIFFRACTION CORRECTIONS TO RELATE MEASUREMENTS THROUGH LIQUID-SOLID INTERFACES TO INFINITE MEDIUM SCATTERING AMPLITUDES

R.B. Thompson, T.A. Gray, D.K. Hsu and J.H. Rose
Ames Laboratory, USDOE
Iowa State University
Ames, IA 50011

Elastic wave scattering calculations often predict the angular and frequency dependence of the spherically spreading waves emanating from the scatterer which has been illuminated by a plane wave. However, a common experimental configuration uses a finite aperture transducer which illuminates the object via mode conversion through a liquid-solid interface and detects the scattered signals via reciprocal processes. Therefore, neither plane wave illumination nor detection of the spherically spreading component of the scattered fields is exactly accomplished. This paper describes a set of approximate corrections which has been developed to account for the diffraction, refraction and focussing effects when the beam passes through planar or curved interfaces. These approximations allow the experimentalist to directly relate measurements to theoretically predicted absolute scattering amplitudes. Use of these corrections will be illustrated by comparing the scattering amplitudes deduced from measurements on a disk-shaped sample containing an oblate spheroidal cavity with those predicted by T-matrix calculations for both the cases of L$\rightarrow$L and T$\rightarrow$T scattering. The correction factors, combined with theoretical scattering amplitudes, allow the prediction of the probability of nondestructively detecting cracks in structural materials. Further, they allow one to estimate the degradations in the inverse Born approximation due to diffraction and focussing in realistic measurement geometries.

NOTES

Tues., 4:05 p.m.

PANEL DISCUSSION

Moderator: R.E. Kleinman, University of Delaware

Panel Members:
R.F. Harrington, Syracuse University
P.C. Waterman, Center for Science and Technology, Inc.
J.D. Achenbach, Northwestern University
L.B. Felsen, Polytechnic Institute of New York
R.B. Thompson, Ames Laboratory

NOTES

Weds., 8:30 a.m.

UNIMOMENT METHOD FOR ELECTROMAGNETIC WAVE SCATTERING

K.K. Mei and T.M. Kvam
Department of Electrical Engineering
University of California, Berkeley
Berkeley, CA 94720

The purpose of this paper is to give sufficient details of the application of the Unimoment Method so that an uninitiated reader can start on his own and apply the method to problems of his special interest.

The steps leading to a successful application of the Unimoment Method include (1) Fundamentals, (2) Mesh generation and node numbering scheme, (3) Loading of equations, (4) Sparse matrix inversion, and (5) Boundary matching.

Several examples of electromagnetic wave scattering are included.

NOTES

Weds., 9:30 a.m.

A HYBRID FINITE ELEMENT - EIGENFUNCTION METHOD FOR ELASTIC WAVE SCATTERING PROBLEMS

V.K. Varadan, V.V. Varadan and J.H. Su
Wave Propagation Group
Department of Engineering Mechanics
The Ohio State University
Columbus, OH 43210

A finite element eigenfunction method (FEEM) is proposed for the solution of elastic wave scattering problems. A scatterer of arbitrary shape (either an inclusion, void or rigid scatterer) is enclosed in a sphere (or circle for 2-D problems). A finite element approximation is invoked to describe the field within the sphere. Outside the sphere, the total field is represented as the sum of the incident and scattered fields. The scattered field is expanded in outgoing vector spherical functions with unknown coefficients. Unlike conventional FEM, the field in the sphere is expanded in a set of eigenfunctions with unknown coefficients. These eigenfunctions are solved for at each nodal point by conventional FEM using each of the vector spherical harmonics in turn as an applied field on the sphere. Then the two sets of coefficients are solved for by demanding the continuity of the field and its partial derivatives across the sphere. Our approach is compared with similar approaches proposed by K.K. Mei, C.C. Mei, S.K. Datta, B. Goetschel, etc. Numerical results showing comparisons with the T-matrix approach will be presented for 3-D axisymmetric scatterers and cylinders of arbitrary cross section.

NOTES

Weds., 10:00 a.m.

FINITE ELEMENT-BOUNDARY INTEGRAL FORMULATION FOR ELECTROMAGNETIC SCATTERING

M.A. Morgan
Naval Postgraduate School
Monterey, CA 93940

C.H. Chen
COMSAT Laboratories
Clarksburg, MD 20734

S.C. Hill and P.W. Barber
University of Utah
Salt Lake City, UT 84112

A new formulation is described which combines the most robust attributes of the volume finite element and surface integral equation approaches to electromagnetic boundary value solutions. The result is a numerical technique which may be applied to scattering problems involving configurations having metallic surfaces and inhomogeneous penetrable material situated in either open or closed spatial regions. This is accomplished by way of coupling internal region finite element modal field solutions to equivalent currents on the surrounding boundary surface through an appropriate surface integral equation. The method is demonstrated for the special case of scattering by axisymmetric inhomogeneous penetrable objects. Example numerical calculations are presented for validation of the procedure and potential problem areas are discussed.

NOTES

Weds., 10:20 a.m.

A NEW HYBRID T-MATRIX - BOUNDARY ELEMENT APPROACH FOR SCATTERING OF WAVES BY ELASTIC SHELLS IN WATER

K. Eswaran, V.K. Varadan and V.V. Varadan
Wave Propagation Group
Department of Engineering Mechanics
The Ohio State University
Columbus, OH 43210

The scattering of acoustic waves by thin elastic shells of revolution submerged in a fluid is of interest in diverse applications. The conventional T-matrix approach for a layered elastic scatterer submerged in water becomes numerically unstable under two conditions: (a) the thickness of the layer becomes small, and (b) the aspect ratio increases. In order to overcome these difficulties a new method is presented using the concept of a dynamic, frequency dependent impedance for the elastic shell. The impedance matrix is calculated numerically by boundary element method using the shell theory of elasticity. The scattering problem itself becomes a completely scalar one by using impedance boundary conditions on the shell. Numerical results will be presented for the case of a finite cylindrical shell with spherical endcaps submerged in water.

NOTES

Weds., 10:55 a.m.

EXPLOITING THE LIMITING AMPLITUDE PRINCIPLE TO SOLVE SCATTERING PROBLEMS

G.A. Kriegsmann
The Technological Institute
Northwestern University
Evanston, IL 60201

A numerical method for solving reduced wave equations will be described. This robust technique is basically a relaxation scheme which exploits the limiting amplitude principle. It is easy to implement: it requires no manipulations of special functions, no surface integrations, and no matrix inversions. For this reason and the fact that the method is based on a very intuitive and physical principle, it will be very useful to scientists and engineers concerned with direct scattering problems. Modified radiation conditions, which allow smaller numerical domains, will also be discussed. Several model problems will be presented.

NOTES

Weds., 11:15 a.m.

COMPARISON OF THE KIRCHHOFF APPROXIMATION WITH EXACT SCATTERING THEORY FOR CRACKS

A.N. Norris
The Technological Institute
Northwestern University
Evanston, IL 60201

The Kirchhoff approximation (physical optics, physical elastodynamics) models the field on a scatterer as simply the incident plus the specularly reflected field. We consider the applicability of the Kirchhoff approximation to scattering by cracks in elastic solids. The field scattered by a slit with a normally incident longitudinal wave is computed using the exact integral equation and the Kirchhoff approximation. The Kirchhoff theory is shown to give reasonable agreement with exact theory, the longitudinal scattered field faring better than the transverse. At high frequency, the Geometrical Theory of Diffraction (GTD) yields as asymptotic approximation to exact theory. By analogy with exact theory, a full three-dimensional Kirchhoff-based Geometrical Theory of Diffraction (KGTD) is developed. The two diffraction theories are compared by looking at their respective diffraction coefficients, which depend only upon the incident and diffracted ray directions. Agreement is exact at the angles corresponding to reflection and shadow boundaries, while at other angles KGTD does unexpectedly well. A major failing of KGTD is that, unlike GTD, it does not satisfy reprocity. This can be corrected for, but the effect upon the diffraction coefficients is minimal. Some other inexact diffraction theories are discussed.

NOTES

Weds., 11:35 a.m.

ELASTIC-WAVE SCATTERING BY SURFACE CRACKS

W.M. Visscher
Los Alamos National Laboratory
Los Alamos, NM 87544

The theory of scattering by a crack on or near a surface of a bounded elastic medium is developed, using a boundary-integral representation (BIR) method. The BIR involves integrals of the COD over the surface of the crack and of the scattered displacement over the boundary of the elastic medium. The latter can be algebraically eliminated and the BIR equations may then be solved by expanding the COD in a set of functions on the crack surface. The coefficients of the expansion are the unknowns in a linear system of equations. The formalism is developed for a 3d crack in an elastic half-space and in a slab geometry. Numerical results are obtained for the 2d case; a flat ribbon crack perpendicular to and on or near a plane surface scatters sagittally incident SH, SV, or P bulk waves and Rayleigh surface waves. Cross-sections for scattering into each of these modes will be presented as functions of incident angle, frequency, and depth of crack edge. Progress on the implementation of the theory for 3d flat cracks of arbitrary shape and orientation in half-space or slab geometry will be reported.

NOTES

Weds., 11:50 a.m.

THE APPLICATION OF ITERATIVE METHODS FOR THE SOLUTION OF SCATTERING PROBLEMS

T.K. Sarkar, S.M. Rao, and S.A. Dianat
Rochester Institute of Technology
Rochester, NY 14623

The approximate methods of solving integral and integro-differential equations of electromagnetics are varied in respect to the ideas lying at their foundation. A number of methods (variational method, Rayleigh-Ritz method, Galerkin's method, method of moments, method of least squares, and so on) has been elaborated. At the same time the analysis of these methods, particularly in electromagnetic theory, has not advanced far. Most methods have remained without any theoretical analysis and have only been verified by their effectiveness in individual examples.

A new class of numerical methods is proposed in this presentation for the solution of electromagnetic scattering problems. The principal distinction between the iterative methods and the method of Rayleigh-Ritz, Galerkin's, and the method of least squares is that the sequence of approximations is not obtained in a form selected a priori but in a form determined by the problem itself.

During the theoretical investigation of every approximate method, the following three problems generally arise, in the order of increasing accuracy and difficulty:

a) the establishment of convergence,
b) the investigation of the rapidity of convergence,
c) an effective estimate of error.

The solution of these problems is quite complex and demands a special individual approach in each instance.

In this paper we present the mathematical foundations of iterative method and apply it to the solution of:

(1) Electrostatic Problems
(2) Electromagnetic Problems
(3) Computation of impulse responses from given input and output data.

It is noted that this class of iterative methods requires considerably less computer storage than the method of moment formulation using subdomain expansion and testing. Since these are iterative methods, a good guess may considerably reduce the computation time.

NOTES

Weds., 1:30 p.m.

THREE-DIMENSIONAL SCATTERING OF PULSED ELASTIC WAVES BY A PENETRABLE OBSTACLE (INTEGRAL-EQUATION TECHNIQUE)

A.T. de Hoop
Laboratory of Electromagnetic Research
Department of Electrical Engineering
Delft Institute of Technology
Delft, The Netherlands

The integral-equation formulation of the three-dimensional scattering of pulsed elastic waves by a penetrable obstacle is discussed. First of all, it is shown how a full Fourier/Laplace-transform technique leads to the appropriate source representations of the elastodynamic field quantities. In them, the proper contrast functions that contain the constitutive parameters of the obstacle in contrast with those of the surrounding medium occur. For inhomogeneous obstacles, the field representations lead to domain integral equations from which the elastodynamic field in the obstacle can be calculated. Besides the domain integral equation, homogeneous obstacles admit a boundary integral-equation formulation in which the kernel functions contain the elastodynamic properties of the obstacle as well as those of the surrounding medium in a certain fashion. The selection of a proper subset of these latter equations is discussed. Secondly, we stress the importance of an error criterion in case the relevant integral equations cannot be solved exactly (i.e. analytically). For practical application, the integrated square error of the residual function in the numerical (i.e. approximate) solution of the discritized integral equation is an attractive choice. Using this error criterion, an iterative technique of solving the pertaining equation is developed. Since in many circumstances the requirements on storage capacity associated with the direct solution of the large systems of algebraic equations arising from the discretization of three-dimensional scattering problems exceed the possibilities of all but the largest computer systems, iterative techniques are attractive in that storage requirements are decreased at the cost of increasing computation time. Numerical results are presented for the scattering of obstacles of simple, polyhedral shapes.

NOTES

Weds., 2:20 p.m.

SPECIAL RESPONSE WAVEFORMS - CAVITY AND RELATED STRUCTURES

D.L. Moffatt, N. Wang, and C.Y. Lai
The Ohio State University
Columbus, OH 43210

Finite and semi-infinite circular waveguides, loaded and unloaded, the thin circular disc and the circular loop are structures whose electromagnetic scattering properties have related features. These relationships are most distinct if the canonical response waveforms of the objects are examined. The canonical response waveforms are the responses of the object to plane wave excitations with shock, step and ramp time dependence. Comparisons of these real, time-dependent waveforms for the above objects are made to illustrate both identical and similar features.

The electromagnetic response of an object to an aperiodic excitation consists of first a forced response as the interrogating wavefront moves across the object and then a natural or free response as the wavefront moves beyond the object. This paper is concerned with the natural or free response portion of the response waveform, which can be characterized by the complex-natural resonances of the target in question. Procedures for using such resonances in a target recognition procedure have been suggested (D.L. Moffatt and R.K. Mains, IEEE Trans. Antennas Propagation 23, 358-367, 1975). In this paper several different approaches for isolating the complex natural resonances of an object are demonstrated. The methods appropriate for application to measured data, eigenanalysis and rational function fits, are compared under noisy conditions.

For cavity-type structures, a method of combining low frequency scattering data with high frequency asymptotic scattering data to obtain models appropriate for scattering computations in the resonance region of the object is demonstrated. The method, which utilizes both physical constraints and moment conditions on canonical response waveforms, is not new (E.M. Kennaugh and D.L. Moffatt, Proc. IEEE 53, 893-901, 1965), but has not previously been applied to cavity structures and cavity structures with loads.

A special interrogating signal which results in a unique forced response and zero free response, is the K-pulse, (E.M. Kennaugh, IEEE Trans. Antennas Propagation 29, 327-331, 1981). Examples of the K-pulse and responses for several of the above targets are given.

NOTES

Weds., 2:40 p.m.

AN EXTENDED BOUNDARY CONDITION METHOD FOR ANALYZING MODES OF DIELECTRIC WAVEGUIDES

N. Morita
Department of Communication Engineering
Osaka University
Osaka, Japan

A method based on the extended boundary condition method is presented for analyzing guided modes of dielectric waveguides of arbitrary cross-sectional shape. Numerical integration needed in this method is only over the boundary periphery line of the waveguide. Nevertheless, it is applicable to waveguides with any refractive index difference between core and cladding ranging from negligibly small to considerably large differences, as well as to certain types of waveguides with inhomogeneous cores. Approximate formulas for the case of weakly guiding are also derivable from the general basic set of equations presented. Numerical examples are given to verify the usefulness and accuracy of this method.

NOTES

Weds., 3:00 p.m.

ELECTROMAGNETIC WAVES IN A CYLINDRICAL WAVEGUIDE WITH PERIODICALLY VARYING CROSS SECTION

A. Boström
Institute of Theoretical Physics
Göteborg, Sweden

Electromagnetic waves in a rotationally symmetric and perfectly conducting waveguide with a periodically varying cross section is considered. Using the null field approach the problem is reduced to a rather complicated secular equation, which is then readily solved numerically. In particular, for a radius that varies sinusoidally with the axial coordinate the passbands and stopbands of the waveguide are determined. Even for very large variations in radius, small passbands are seen to exist, and probably some passbands exist all the way to where the waveguide is cut off.

NOTES

Weds., 3:35 p.m.

SPECIAL LECTURE:

SOME ASPECTS OF RECENT WORK IN QUANTUM PARTICLE SCATTERING AND ITS RELATION TO WAVE SCATTERING

R.G. Newton
Department of Physics
Indiana University
Bloomington, IN 47405

NOTES

Weds., 4:35 p.m.

PANEL DISCUSSION

Moderator: A.T. de Hoop, Delft Institute of Technology

Panel Members:
R.G. Kouyoumjian, The Ohio State University
R. Mittra, University of Illinois
W.M. Boerner, University of Illinois
R.G. Newton, Indiana University
K.K. Mei, University of California, Berkeley

NOTES

Thurs., 8:30 a.m.

INVERSE MODELLING IN REMOTE SENSING

W.M. Boerner
University of Illinois, Chicago
Chicago, IL 60680

Inverse methods have become a fundamental tool in the physical sciences for remotely sensing unknown objects and for reconstructing their physical properties. They have been developed in many otherwise diverse fields of physical sciences where the characteristics of a medium are estimated from experimental data in a given situation. Interdisciplinary applications of inversion techniques are drawing increased attention, and, therefore, a brief overview of several relevant methods useful to inverse modelling in remote sensing will be considered, including mathematical treatments, geophysical inverse problems, medical imaging and methods developed in electromagnetic radar target mapping and imaging.

Inverse modelling has become an integral part of aeronomic remote sensing using both passive and active wave sounding where usually the Born and Rytov approximations for slowly varying index profile are relevant. Whereas, in the microwave region coherent methods developed in radar imaging and target adaptive scatterometry are more likely to be used, in the infrared and optical regions incoherent properties need to be taken into consideration as well.

NOTES

Thurs., 9:30 a.m.

ELASTIC WAVE INVERSE BORN APPROXIMATION - RECENT ADVANCES

J.H. Rose
Ames Laboratory, USDOE
Iowa State University
Ames, IA 50011

In recent years the Born approximation has served as the basis for a rather successful method of determining the geometric feature of flaws in elastic materials. We will review recent advances in the study of the inverse Born approximation (IBA) with an eye towards future advances and towards an understanding of its wide range of success. The review will include a synopsis of: rigorous results, connections to other theories, experimental tests and verification, the use of computer experiments, optimization of laboratory techniques, and attempts to automate and establish the practical limits of the algorithms utility. Several examples will be mentioned in somewhat greater detail. These include: 1) the fact that the IBA can be used to exactly determine the size, shape and orientation of a wide class of voids given the exact back-scattered amplitudes at all frequencies and all angles of incidence; 2) the experimental determination of the size, shape and orientation of a surface inclusion; and 3) the use of the IBA to determine the geometric features of a flaw in a jet engine part.

This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Defense Advanced Research Projects Agency and the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

NOTES

Thurs., 10:00 a.m.

ELASTIC WAVE INVERSE SCATTERING THEORY

A.J. Devaney
Schlumberger-Doll Research
Ridgefield, CT 06877

This paper addresses the problem of deducing the elastic properties of three-dimensional inhomogeneous objects from elastic scattering experiments. Specific attention is devoted to the case of an elastically isotropic object imbedded in a homogeneous and isotropic elastic medium and insonified by either a monochromatic compressional or transverse plane wave. The inverse scattering problem for this case is shown to reduce to solving a certain nonlinear integral equation which relates the scattered field data (T matrix) to the unknown elastic properties of the object. A perturbational solution of this equation is obtained that yields approximate reconstructions of weakly scattering objects for cases where the on-shell components of the T matrix are known from a sequence of scattering experiments employing incident plane waves having different directions of propagation. In its lowest order the perturbational solution is shown to correspond to the first Born approximation. For this case a new reconstruction method is presented that is in the form of an integral transform of the object's T matrix assumed to be known everywhere on the energy shell.

NOTES

Thurs., 10:45 a.m.

SOME RECENT RESULTS IN PROBABILISTIC INVERSE SCATTERING

J.M. Richardson and K.A. Marsh
Rockwell International Science Center
Thousand Oaks, CA 91360

The probabilistic approach to the inverse problem in the scattering of elastic waves is discussed and contrasted with other approaches. The central feature of the probabilistic approach is a stochastic measurement model involving statistical ensembles of scatterers and measurement errors. To illustrate the role of the scatterer ensemble we discuss two non-parametric problems in detail, namely: a) the case in which the scatterer ensemble is represented by a spatially stationary Gaussian random process, and b) the case in which the scatterer is an inclusion of known material but unknown boundary.

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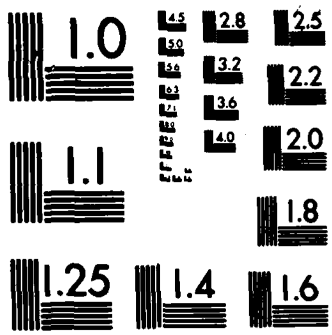

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Thurs., 11:05 a.m.

RIGOROUS INVERSE SCATTERING THEORY FOR THE TIME-DEPENDENT WAVE EQUATION

B. DeFacio
Department of Physics and Astronomy
University of Missouri, Columbia
Columbia, MO 65211

The inverse scattering theory of the time-dependent elastic wave equation is much less developed than the inverse theory for the Helmholtz equation. Since for many problems in geophysics and non-destructive evaluation the ill-posedness associated with deconvolution of noisy data can be avoided by working in the time domain, this is somewhat surprising. As observed by Burridge, Lee and Rose and Richardson, the causal structure is particularly powerful.

The wave equation in two space dimensions is rigorously studied. Existence and uniqueness proofs of the solution to the Marchenko-type inverse scattering problem are presented for the interesting case without initial quiescience, i.e. $\phi(t)$ non-vanishing in

$$\left.\left(\vec{U}_{,x_2}\right)(\vec{x},t)\right|_{x_2=0} = \delta(x_1)\ \left[\delta(t) + \phi(t)\right]\varepsilon_2 \ .$$

The existence proof is accomplished by converting the system pde's to integral equations and estimating them using Sobolev space methods. The uniqueness proof follows from a contraction mapping argument. Preliminary error estimates will be presented and a comparison to earlier studies will be given.

NOTES

Thurs., 11:25 a.m.

IMAGING TECHNIQUES IN ELECTROMAGNETICS

J.D. Young
Electroscience Laboratory
Department of Electrical Engineering
The Ohio State University
Columbus, OH 43212

A set of techniques for creating three-dimensional images for known classes of targets based on their electromagnetic backscattered transient response has been devised and investigated. Recent transient signature measurements with improved bandwidth and resolution have been obtained. This presentation will discuss the features of the experimental transient response signatures, and discuss the impact on image quality of signature bandwidth and accuracy.

NOTES

Thurs., 11:45 a.m.

THE INVERSE SCATTERING PROBLEM OF THE DUAL POLARIZATION DIFFERENTIAL REFLECTIVITY RADAR TECHNIQUE

T.A. Seliga and K. Aydin
Atmospheric Sciences Program and
Department of Electrical Engineering
The Ohio State University
Columbus, OH 43210

V.N. Bringi
Department of Electrical Engineering
Colorado State University
Ft. Collins, CO 80523

The dual polarization differential reflectivity (Z_{DR}) radar technique utilizes the volumetric backscattered power in two linear polarization states, horizontal and vertical, to derive quantitative and qualitative information on storm environments. For example, these signals combine to yield important information on rainfall characteristics and hydrometeor phase at spatial and temporal scales appropriate to the phenomena. The theoretical basis of the technique is reviewed, and a summary of the results obtained to date is presented. The inversion process depends upon combining a prior knowledge of the physical and electrical properties of the hydrometeor scatterers with the radar measurements. Ways in which this information is used to help interpret the radar observables are noted and demonstrated by example.

NOTES

Thurs., 1:15 p.m.

WAVEFRONT FIELDS IN THE SCATTERING OF ELASTIC WAVES BY SURFACE-BREAKING AND SUB-SURFACE CRACKS

J. Miklowitz
California Institute of Technology
Pasadena, CA 91125

Presented here is a method for deriving the wavefront fields in the scattering of transient elastic waves by surface-breaking and sub-surface cracks. Such wavefront fields, generated by the interaction of incident surface or body waves, should yield most of the important information about the geometries of these cracks. Such information is invaluable to the subject of mechanics in general, and in particular to quantitative non-destructive evaluation (QNDE).

The present problems fall into a class that are nonseparable classically and as such are difficult to solve, the nonseparability stemming from media corners and crack edges. Mathematically, however, the boundary-value and initial-value problems involved can be handled through integral transforms and equations, asymptotics and numerical analysis.

Recently, the present crack problems have been addressed in the literature for the cases of time-harmonic loads and waves, and very useful information for QNDE was obtained. The present work, involving transient loads, waves and wavefronts, is in effect the counterpart of the foregoing time-harmonic cases in the literature for the high frequencies (wavefronts). Further, the present method gives all the scattered wavefront fields, yielding the magnitudes and the geometric positions of the wavefronts about the cracks, hence further important information for QNDE.

NOTES

Thurs., 2:15 p.m.

PANEL DISCUSSION:

FUTURE RESEARCH IN WAVE PROPAGATION AND SCATTERING

Panel Members:
W.A. Flood, U.S. Army Research Office
R.G. Brandt, U.S. Office of Naval Research
N.L. Basdekas, U.S. Office of Naval Research
C. Holland, U.S. Office of Naval Research

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